EARL M. P. LOVEJOY *Department of Geological Sciences, University of Texas at El Paso, El Paso, Texas 79999*

Tectonic Implications of High Level Surfaces Bordering Franklin Mountains, Texas

ABSTRACT

High level, early to mid-Pleistocene piedmont and pediment deposits and surfaces along the southern Franklin Mountains extend out toward bolson fill deposits and surfaces. On the east side of the range, 400 ft (121 m) of post-bolson fill displacement has been reported by earlier workers. There has been no concomitant uplift along the west side of the range. Thus, the range has been tilted during Pleistocene deformation, and uplift has been mainly along the eastern fault. The block rotation of about 2.3 degrees from 0.25 to 2.0 m.y. represents about 6.6 percent of the total block rotation since inception of range tectonics. A constant rate of block rotation indicates a date of inception between 4 and 30 m.y. ago, which agrees reasonably well with the accepted Miocene date of inception of the Rio Grande tectonic trench. Crustal shortening due to tilting indicates tectonic compression associated with orogenic uplift.

INTRODUCTION

The Franklin Mountains are an excellent example of a basin range. They form part of a structural continuity which extends 100 mi from the north end of the San Andres Mountains, and constitute the eastern boundary of the Rio Grande trench at its southern end (Bryan, 1938, Fig. 45, p. 198). They are terminated at their southern end by the Texas lineament. Thus, the range is associated genetically with two major tectonic features of North America.

Work by Richardson (1909), Harbour (1960), and various other workers, did not involve large scale mapping, studies or analysis. The detailed geologic mapping (scale 1:6000 and 1:12000) by the author since 1965 has disclosed data of regional geomorphic and tectonic significance.

This paper presents data pertaining to high level, piedmont slope surfaces of probable early Pleistocene age which have been slightly displaced by faults in the west side of the range and apparently slightly rotated due to range tilting. The area discussed in detail is unique in the range because gravels containing rhyolite locally can be differentiated from older gravels free of or lacking much rhyolite, thus permitting more precise stratigraphic, geomorphic and tectonic evaluation. The rhyolite which underlies the Paleozoic strata has only been recently exposed as an inlier at the Thunderbird. The high level piedmont slope surface has been displaced about 6 ft along piedmont scarplets on the west side of the range in the vicinity of the Thunderbird (Fig. 1; *see* Richardson, 1909; Harbour, 1960; Lovejoy, 1968).

OLDER GEOMORPHIC SURFACES

Geomorphic surfaces in the Franklin Mountains region have been described by Ruhe (1964, 1967), Kottlowski (1958), Hawley (1965), Hawley and Kottlowski (1969), Hawley and others (1969), and Gile and others (1970).

Kottlowski (1958, p. 48) stated that the La Mesa surface near the Franklin Mountain is at an altitude of ". . . about 4,130 feet just west of Cerro de Muleros, and 4,200 feet on flanks of the Franklin Mountain."

Kottlowski (1958, p. 52) described geomorphic surfaces on the east side of the Franklin Mountains in a "relatively cursory" way, commenting on the eastern frontal faulting of as much as 350 to 400 ft reported earlier by Sayre and Livingston (1945). He noted the presence on the east side of the range of ". . . [r]emnants of a still higher level which occur as truncated caliche-capped spurs at altitudes above 4,320 feet one half-mile west of the 4,250 surface." However, he questioned correlation of surfaces on the east side with those on the west because of the

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cited faulting and tilting along the east side of the range. With regards to older geomorphic surfaces near Las Cruces, New Mexico, Hawley and others (1969, p. 58) state that

> . . . basin filling in extensive areas adjacent to the Rio Grande culminated with development of the Jornada and La Mesa geomorphic surfaces, whose respective type areas are the southern Jornada del Muerto Basin and northern Mesilla Bolson. The broad basin floors, generally underlain by Santa Fe fluvial sand and gravel deposits and locally with a thin veneer of eolian cover sands, comprise La Mesa geomorphic surface. Large areas of piedmont slopes (including pediment, alluvial-fan and coalescent fan surfaces) locally overlap or are inset slightly below remnants of La Mesa surface . . . Small remnants of alluvial fans and rock pediments preserved above the Jornada surface along the mountain fronts comprise the Dona Ana surface, which may be a piedmont-slope correlative of La Mesa. All these surfaces are complex, and each may represent several stages of development over a period of time.

Metcalf (1969, p. 162–163) discussed the highest and oldest erosional surface along the eastern slopes of the Rio Grande Valley west of the Franklin Mountains which have been correlated accurately with regional surfaces, citing specific locations for specific surfaces. He referred to his location 13, opposite Western Hills School on Thunderbird Drive (west of the Thunderbird), as an example of the Jornada surface, which ". . . typically is associated with broad piedmont slopes adjacent to mountain fronts, where it occurs on alluvial fans and coalescent fan piedmont. . . . The Jornada Surface locally overlaps the La Mesa surface, hence is slightly younger, although underlying sediments associated with both surfaces are of the upper Santa Fe Group (Kottlowski, 1960) and are, in part, contemporaneous." (*See also* Hawley, 1965, p. 190.)

Metcalf did not specifically discuss the mountain front geometry of these surfaces, limiting himself to details farther down the slope and commenting only generally on the actual range front. Metcalf (1969, p. 163) cites Gile and Hawley (1968) who described both an older Jornada I and a much younger Jornada II surface in regions north of the Franklin Mountains. Metcalf (1969) also notes: "In several places along the west side of the Franklin Mountains, ancient alluvial fans abutting against the mountains, and usually rock-defended towards the valley, may be equivalent to the Dona Ana Surface of Ruhe (1964; 149) or they may only reflect differences in elevation in the individual fans that contributed to the Jornada surface."

Hawley (1965, p. 160) called the Dona Ana surface "A still older [than the Jornada] and much less well-preserved piedmont-slope surface" which "may be a general time correlative of the La Mesa basin-plain surface" (*see* Table 1).

EVIDENCE OF THE HIGH LEVEL SURFACE ON THE WEST SIDE OF THE FRANKLIN MOUNTAINS

Only at the very southern end of the range do the middle Pleistocene Upper Santa Fe group strata flank the Paleozoic strata of the range. In the areas described in this paper the flanking piedmont deposits are either old or recent alluvium. Thus, the evidence of the high level surface extends the datum used for determining tectonic chronology far to the north along the range front. Important examples of the high level piedmont surface on the west side of the range occur on caliche-cemented gravels: (1) west of North Franklin Mountain; (2) west of South Franklin Mountain and also (3) in Tom Mays Park; (4) near Crazy Cat Mountain; and (5) on the east side of the range.

Five specific remnants of importance to this study have been examined in detail. These are termed here the North Franklin Mountain north and south remnants, and the Thunderbird north, middle, and south remnants.

The North Franklin Mountain south remnant (Fig. 2) lies between the new Transmountain Road and the range in a line due west of North Franklin Peak. Its highest elevation is 5500 ft, the highest observed elevation of any of these older surfaces in the Franklin Mountains (determined by altimeter and resection on a topographic map base, scale 1:12000). It lies between two drainages which are more than 90 percent filled with rhyolite from the Thunderbird rhyolite inlier. This older alluvium, however, consists primarily of El Paso limestone, with minor Bliss sandstone and lesser amounts of rhyolite. It is well cemented and thickly coated with caliche and it is 1900 ft long. At an elevation of 5040 to 5100 ft, the southern wash cuts northward across the higher level alluvium and flows north to join the northern wash. This stream capture of originally parallel drainages has occurred west of the bedrock boundary fault of the range. Restoration of the now-dissected

Paleozoic surface necessary to supply the limestone debris requires 200 to 400 ft post-high level erosion of rhyolite in the canyons, but less than 100 ft in the ridges.

The present gradient of the stream south of this remnant is generally 20 percent, and up to 25 percent near the elbow of capture (map data). The gradient of the high level surface is 20 percent above 5150 ft. A slope of 23 percent at 5150 ft is probably a scarplet about 2 to 3 m high. The slope below that is 16 percent. The gravity slope from there to the north-trending wash is 23 percent. The 16 percent slope is covered by a thin veneer of slightly younger rhyolite gravel on top of the older gravel (*see* Fig. 2). The relief between the modern stream and the old surface increases up-stream from 30 ft at the elbow of capture to 120 ft at the upper end of the older surface. Thus, either (1) paleo-gradients were steeper than those of the modern stream because of the differences in rock type as load, or (2) mountain front to basin floor relief in early Pleistocene was greater than that of today[1], or (3) the older deposits have been tilted by range movements.

The north remnant (Fig. 2) does not extend west of the frontal fault. It is similar in lithic composition, degree of calichification, weathering and gradient to the gravel in the south remnant. It is about 100 to 150 ft above the "Jornada" surface in the south end of Tom Mays Park. It is 1200 ft long and slopes 20 percent west. The western end of this remnant lies just east of the supposed trace of the frontal fault. There is no evidence here of a piedmont fault scarplet in this deposit.

A saddle at the north end of Tom Mays Park (Fig. 2), at an elevation of about 5010 ft, formed on calichified gravels which are at least 40 ft thick and lie across the boundary fault of the range, may represent part of this high level surface. It may also be correlated with the "Jornada" surface with which it seems to be in direct continuation, or it might be an older surface merely merged with the "Jornada" surface through slope modification. This part of Tom Mays Park is a broad, barely dissected upland surface which has been "rock defended" (Metcalf, 1969) by the high hills of Permian strata to the west. There is no evidence here of a piedmont fault scarplet.

The Thunderbird north remnant (Fig. 3) lies at the north side of the mouth of a canyon containing two parallel washes a few hundred feet north of the latitude of South Franklin Mountain peak at an elevation of 4900 ft. This is the least preserved of the five remnants and has been most modified by later erosion. The present drainage (consisting of

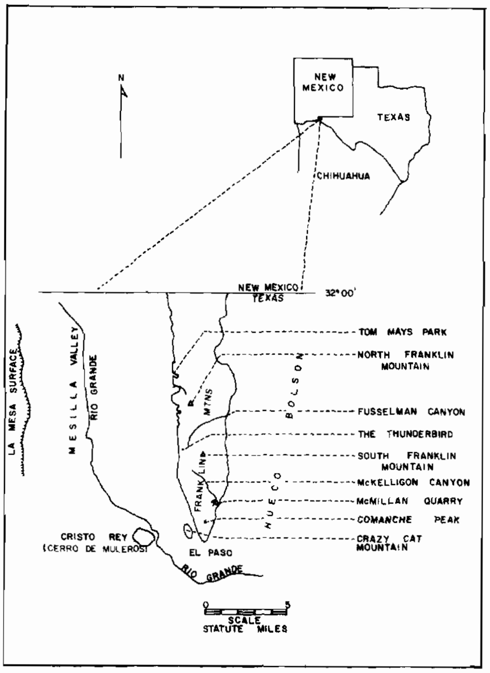

Figure 1. Regional and local index maps.

[1] The basin fill between the Franklin Mountains and the Rio Grande is of undetermined depth. Andesite plugs which intrude Cretaceous strata outcrop and form low hills above the basin fill, and around these low andesite hills Cretaceous strata also outcrop. However, the original heights of these buried andesite-Cretaceous strata hills is unknown. The best estimate of the depth of basin fill in this area is on the order of a few hundreds of feet. Whether the pre-fill stream's gradients would have been reflected in the inclination of the exposed alluvial fan slopes at the mountain front is not known, but it would seem that gradients are more a reflection of stream competency than of earlier local relief. Had there been too much relief for materials of a constant size, deposition would not have occurred and alluvial fans would not have formed on the mountain front. With basin infilling, fan material would have accumulated at a constant slope with constant clast size. Since there is no evidence of change in clast size in the older fan material there would seem to be no reason for a change in fan slope gradient due to change in relief from pre-fill times to Jornada times.

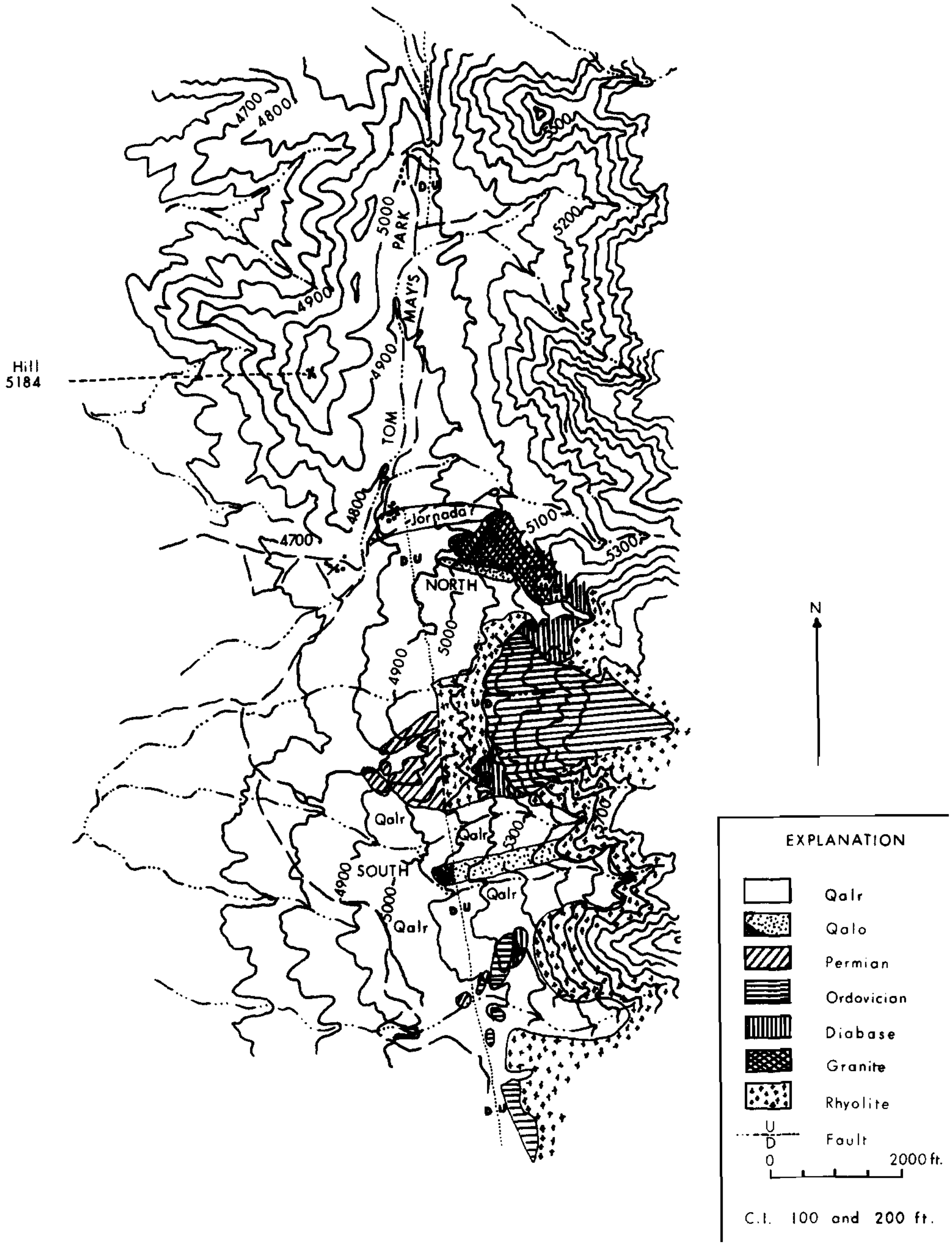

Figure 2. Geologic map of North Franklin Mountain remnants of early to middle Pleistocene piedmont deposits. The geology shown on this map is that pertinent to the problem only. The Jornada surface is shown locally north of the north remnant of older alluvium (Qalo). Qalr is shown only at a few important localities. The frontal fault segments connect beneath alluvium in Tom Mays Park. Heavy stippling in the Qalo in the south remnant represents a slightly younger rhyolite-gravel veneer on the older alluvium between the piedmont fault scarplet at the frontal fault zone and the transverse drainage at the west end of the remnant.

TABLE 1. HIGH LEVEL GEOMORPHIC SURFACES ADJACENT TO THE RIO GRANDE VALLEY, SOUTHERN NEW MEXICO, AND WEST TEXAS

Bolson Fill Units	Bolson Fill Surfaces: Basin–Floor Position	Bolson Fill Surfaces: Piedmont–Slope Position	Age
Post Santa Fe		Jornada II (morpho-stratigraphic unit)	Late Pleistocene
Upper Santa Fe Gp. – Camp Rice Fm.	Jornada I	Jornada I	Mid–Pleistocene
Upper Santa Fe Gp. – Camp Rice Fm.	La Mesa	Dona Ana	
Upper Santa Fe Gp. – Fort Hancock Fm.			

two parallel arroyos in the range) splits due to capture at the mountain front. The southern arroyo drains to the southwest, but the more active northern arroyo drains northwest across the upper part of this remnant as the result of beheading, perhaps along a piedmont scarplet. The remnant consists of highly calichified limestones with only a few fragments of rhyolite visible which are high in the alluvial stratigraphic section. Apparently the rhyolite in the upper part of the canyon was not exposed at the time that the oldest alluvium was deposited. The present maximum gradient of the old surface is 20 percent. There is a small cover of rhyolite-rich gravels which covers the south side of this remnant below 4800 ft (Fig. 3). Extension of the surface formed on the sub-alluvial bedrock up and across the frontal fault is problematical. The alluvium west of the fault lies on exposed Cretaceous limestone and shale. None of the alluvium was found lying on the Paleozoic bedrock east of the frontal fault. The northern (beheaded) stream has cut a canyon up to 100 ft deep through this old alluvium. The southern (non-beheaded) stream has cut only about 30 to 40 ft below this surface.

The Thunderbird middle remnant is the longest and most important of the three Thunderbird remnants (*see* Figs. 3 and 4 for further details). It extends east at least 1500 ft from the western side of the frontal fault where it lies on Cretaceous shale, across the boundary fault and onto the lower Ordovician (El Paso) limestone of the range. It extends from an elevation of at least 4900 ft (near the power line) up to an elevation of about 5140 ft (determined by altimeter and resection). However, the sub-alluvial limestone bedrock ridge on which this gravel is found continues upward to the east as an erosional surface which extends essentially along the same grade to an elevation of about 5450 ft where this ridge ends against a rugged cliff. There is no rhyolite from the rhyolite inlier in the older alluvium, which consists primarily of clasts of Ordovician (El Paso) limestone. The modern stream gravel is composed of about 90 percent rhyolite. North-south transverse profiles across the present canyon show that it is about 100 ft deeper than the top of the old alluvium at the boundary fault, and about 100 ft deep at the upper end of the old alluvium. Restoration of 100 ft of rhyolite would bring the entire drainage basin surface almost to the restored rhyolite-Ordovician contact.

The average gradient of the older alluvial surface is a measured 26 percent across the frontal zone. The gradient of the present stream downcutting in bedrock adjacent to the older remnant is also a measured 26 percent. However, this older surface is offset down on the west about 6 ft at an elevation of 4960 ft. This is here interpreted to be the erosionally modified remnant of a piedmont scarplet. The average grade across the modified scarp is 33 percent. The average grade above and below it is 23 percent. The slope of

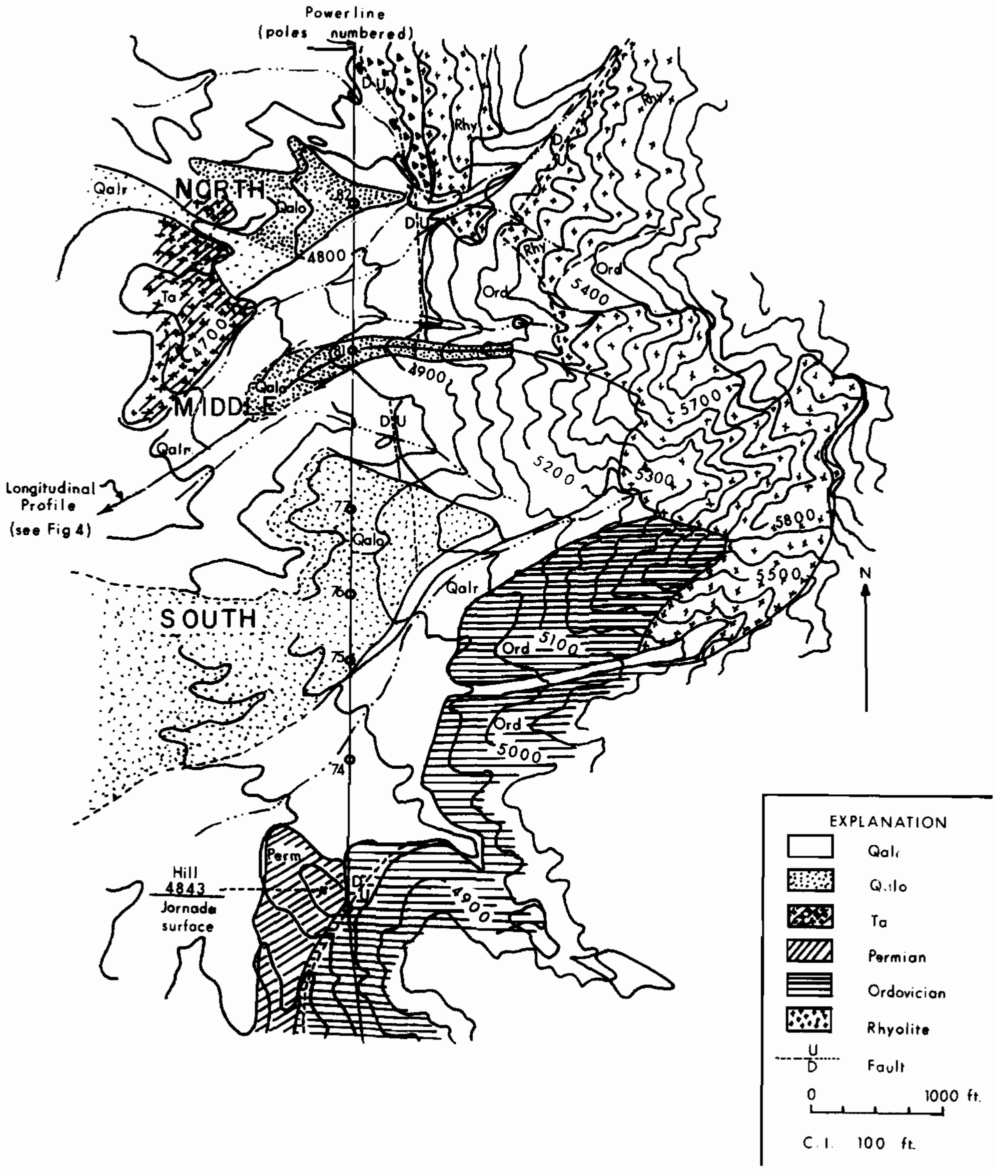

Figure 3. Geologic map of South Franklin Mountain remnants of early to middle Pleistocene piedmont deposits. Qalr in the north remnant is part of the Jornada II surface. Elsewhere, Qalr refers to alluvium in modern washes. The longitudinal, curved profile along the middle remnant is shown in detail in Figure 4.

the alluvium west of the power line is 27 percent due to slope modification; there are no rhyolite gravels.

It is important to note that nowhere on the west side of the Franklin is there any evidence of piedmont fault scarplets on geomorphic surfaces younger than those described here.

The Thunderbird south remnant is the largest of the three Thunderbird remnants. A piedmont scarplet (the first discovered in this study) trends 750 ft across the older alluvium at an elevation of about 4960 ft, and is obvious in the field (especially under low-angle, eastern sunlight) and on aerial photographs. An estimated 6 ft of displacement down on the west is apparent.

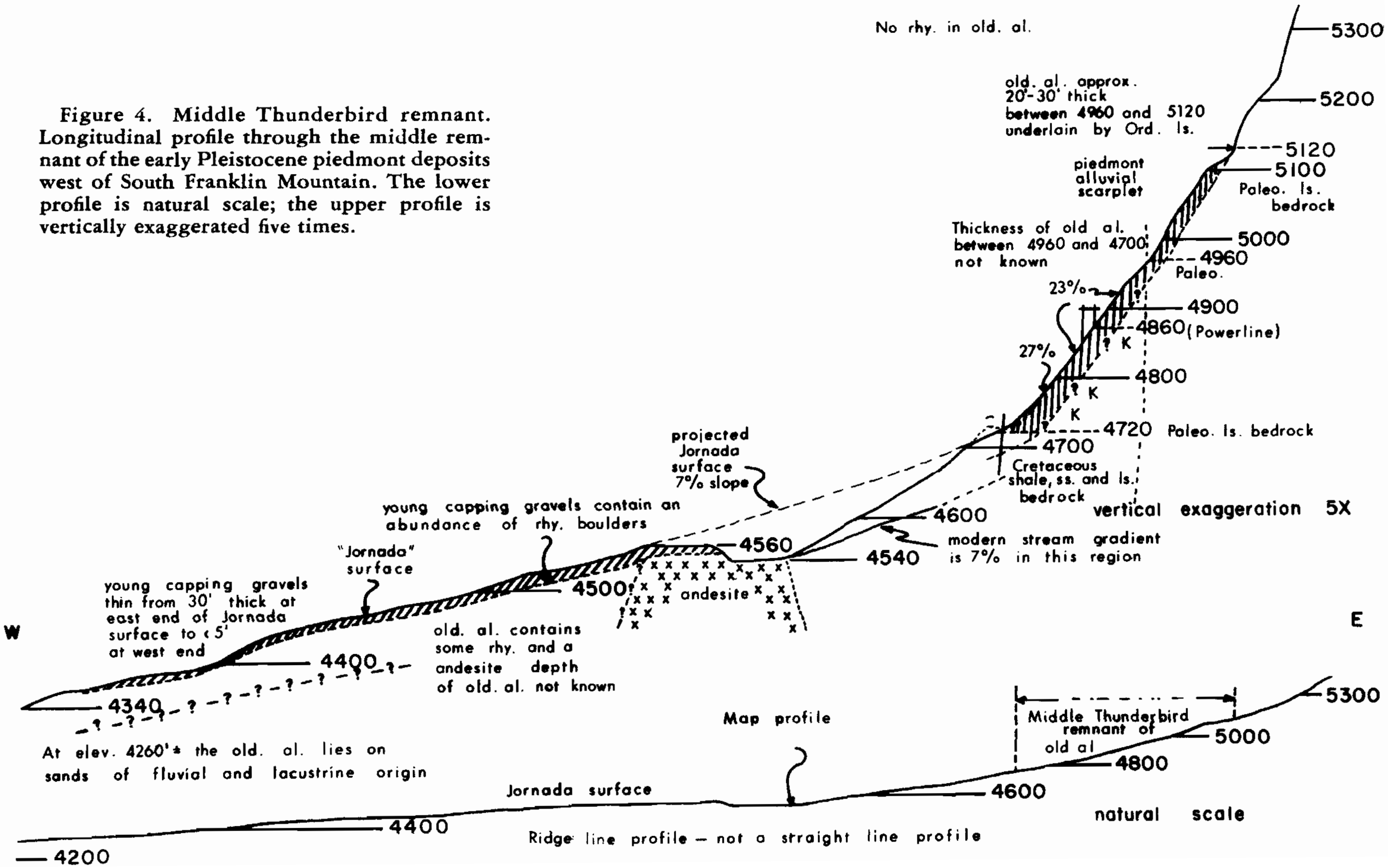

Figure 4. Middle Thunderbird remnant. Longitudinal profile through the middle remnant of the early Pleistocene piedmont deposits west of South Franklin Mountain. The lower profile is natural scale; the upper profile is vertically exaggerated five times.

The old alluvium is composed of clasts of both rhyolite and Ordovician limestone as is the alluvium in the modern canyon to the south which drains the extensively eroded Thunderbird inlier of rhyolite. The rhyolite content of the alluvium decreases downward. About 40 ft above the basal contact on Cretaceous shale the rhyolite clasts disappear. The gradient of the remnant surface is between 18 and 20 percent. The modern stream to the south has a gradient of 13 to 14 percent. This older alluvium is not capped by rhyolite-rich gravels.

The rhyolite of this older alluvium is fractured, as if frost riven. It is not deeply weathered, but it is easily broken with a hammer. The rhyolite in the modern wash is solid and unfriable. Large boulders of the rhyolite are well exposed on the upthrown side of the piedmont scarplet where they lie as lag boulders, left by ellutriation of the finer materials. Chert on the limestone cobbles and boulders stands out with as much as 1 cm of relief on what must have once been fairly smooth stream-worn clasts. Caliche is up to 4 mm thick on many of the limestone boulders.

Where the modern west-flowing arroyo turns more southerly, it seems to follow the now obliterated trace of the piedmont scarp, once again suggesting stream course guidance by the scarplet.

A deep canyon on its northern side is eroding headward in Paleozoic bedrock east of the border fault, indicating a geologically imminent beheading of the southern remnant such as has already occurred in the north remnant.

RELATIONSHIP OF THE JORNADA SURFACE AND THE OLD GRAVEL REMNANTS

In an arroyo just west of the surface described as location 13 by Metcalf (1969, p. 163), the pediment gravels underlying the Jornada surface overlie Camp Rice (Hawley, 1970, p. 24; Strain, 1966, 1969a, 1969b) deltaic and fluviatile sands and silts. The gravels there, which are about 20 m thick, consist of two zones, a lower, thicker unit, and an upper, thinner unit. The lower, thicker unit, about 18 to 19 m thick, consists of very well caliche-cemented gravels, generally of cobble size with but few boulders, containing only a small amount of rhyolite. This lower unit has been correlated by mapping over an area of several square miles west of the Thunderbird. Overlying this thick unit is a thinner, much less cemented gravel deposit consisting of rocks up to boulder size, as much as 1 m across, composed of a substantial portion (20 to 40 percent) of rhyolite and from 1.5 m to about 3 to 5 m thick (apparently not derived from the subjacent gravel zone but deposited across it). The rhyolite boulders fracture easily due to long weathering. This surface has been traced out by walking from the "Jornada" surface location 13 cited by Metcalf eastward to the base of the Franklin Mountains where it stops abruptly (Fig. 3) at the base of the Thunderbird middle remnant.

Viewed along a horizontal line from the north remnant, the north, middle, and southern remants lie in a common surface. Although this surface now merges topographically with Metcalf's "Jornada" surface, the merger is neither an alluvial nor pediment surface but a gravity slope which had modified the topography formed on the older materials. The western end of the middle remnant has a gravity slope of 27 percent westward which is much steeper than that of the adjacent graded wash slopes and drainages. The "Jornada" surface can be extended to the base of the middle remant at an elevation of 4640 ft (Fig. 4). The "Jornada" surface has abundant rhyolite boulders on it. The older middle remnant alluvium contains no rhyolite above this elevation. This nickpoint (Fairbridge, 1968, p. 991) at 4640 ft is sharp and easily seen in the field. Thus, the older (rhyolite-free) alluvium of the middle remnant has been cut at its base by the "Jornada" surface (of rhyolite-rich boulders). The gravity slope which now joins the present graded, rhyolite-boulder-rich "Jornada" surface (slope of about 17 percent) with the older rhyolite-free middle remnant surface (slope of 23 percent) is a modern gravity slope (27 percent) which is gradually wearing away the middle remnant older alluvium. The present arroyos continue eastward to bedrock at slopes of about 7 percent. This nickpoint thus represents the zone of destruction of the older rhyolite-poor gravels by the "Jornada" pediment (rhyolite-rich gravels). This distinct relationship is good evidence that Metcalf's "Jornada" *surface*, which is the piedmont slope equivalent of the basin-fill La Mesa *surface* (Hawley, 1965, p. 190), is younger and lower than the older *surfaces* (rhyolite-poor gravel) under discussion in this paper.

The younger, upper, rhyolite-rich, bouldery gravels thin westward to thicknesses of less than 1.5 m near the present Chaparral subdivision 1 mi to the west at an elevation of about 4250 ft. The lower unit (rhyolite-deficient) is about 15 m thick in the region studied, from mountain front to the Chaparral subdivision, although it thins westward down the slope in this area. Apparently, the rhyolite-rich boulder gravels were emplaced in a pedimentation stage which may have destroyed or simply covered slightly the land forms produced on the top of the earlier rhyolite-poor pedimont gravel deposits; thus, the remnants discussed here may be part of the older surface.

From the Thunderbird north remnant one may look horizontally south at the middle and southern remnants at the same elevation, and see that the top of hill 4843 beyond them is also concordant with this extended high surface (Fig. 3). This flat-topped hill, formed of brecciated Permian strata, may represent a more resistant part of a pedimented bedrock surface eroded in concordance with the alluviated surface now manifest by the older alluvium surfaces under discussion. Metcalf's "Jornada" surface extends continuously up to the base of this hill 4843 to an elevation of about 4700 ft. The hill 4843 surface may have formed earlier. It is higher than the rhyolite-rich surface gravels. If hill 4843 is really a part of this older surface there would appear to be a great difference in age between that older surface and Metcalf's "Jornada" surface. Thus, the Thunderbird remnants described here may be either parts of the Jornada I gravels and modified surface, parts of the Dona Ana surface, or parts of a still older surface that may be a correlative of the Rincon surface of Hawley and others (1969). All of these are as old or older than the top of the basin fill (upper Santa Fe Formation) which is generally of mid-Pleistocene age (Hawley and others, 1969).

Other caliche-cemented gravels occur in small patches in many of the canyon walls along the west side of the range. An especially well-developed surface formed on gravels lies west of Ranger Peak in the southern part of the range at an elevation of 4540 ft. This is about 300 ft above the La Mesa surface mentioned by Kottlowski (1958) and seems to fit the description of the Dona Ana surface as well (Hawley and others, 1969), but it may be a remnant of the Jornada I surface. This gravel remnant forms a divide between north-flowing streams on the east side of Crazy Cat Hill. The gravels lie on a remnant of the pre-upper Santa Fe Group Crazy Cat slide (Lovejoy, 1968) which here lies across the western border fault of the range. This slide might be confused with the high level surface but the internal structure shows the difference. Neither the gravel nor the slide have been displaced appreciably by post-slide fault movement. South of Crazy Cat Mountain, unfaulted strata of early to mid-Pleistocene age (Strain, 1966) also cover the border fault.

EVIDENCE OF THE HIGH LEVEL SURFACE ON THE EAST SIDE

Several remnants of this high level surface occur on the east side of the range south of McKelligon Canyon (Fig. 5). Significant remnants occur farther north in the range, but data for these have not been included for this report because they lie on separate structural blocks (Richardson, 1909, p. 8).

The three principal occurrences may be called the Comanche Peak, McMillan Quarry, and Southern McKelligon Canyon remnants.

East of Comanche Peak is an old, caliche-coated alluvial slope composed primarily of El Paso limestone debris which extends across a surface of Red Bluff granite that underlies the Paleozoic strata. The highest point on this deposit is 4440 ft; a fairly flat surface occurs at about 4380 ft. The short slope above 4300 ft is inclined about 12 percent east, and the present elevation of Hueco Bolson east of the range is about 4000 ft.

West of McMillan Quarry is an old, caliche-covered alluvium consisting of El Paso limestone and Bliss sandstone fragments lying on top of Red Bluff granite, which rises to 4800 ft. The surface slopes east 14 percent.

In southern McKelligon Canyon, 3000 ft north of the McMillan Quarry remnant and at the south end of the high cliffs of Red Bluff granite, is another old caliche-cemented limestone and sandstone boulder deposit lying on Red Bluff granite. The boulders are larger here than in any of the other remnants studied. The maximum elevation of the deposit is 5040 ft. The surface slopes east about 20 percent.

As Kottlowski noted, correlation on the basis of elevation is difficult, but these represent the highest caliche-cemented gravel remnants on the east side of the range. Their

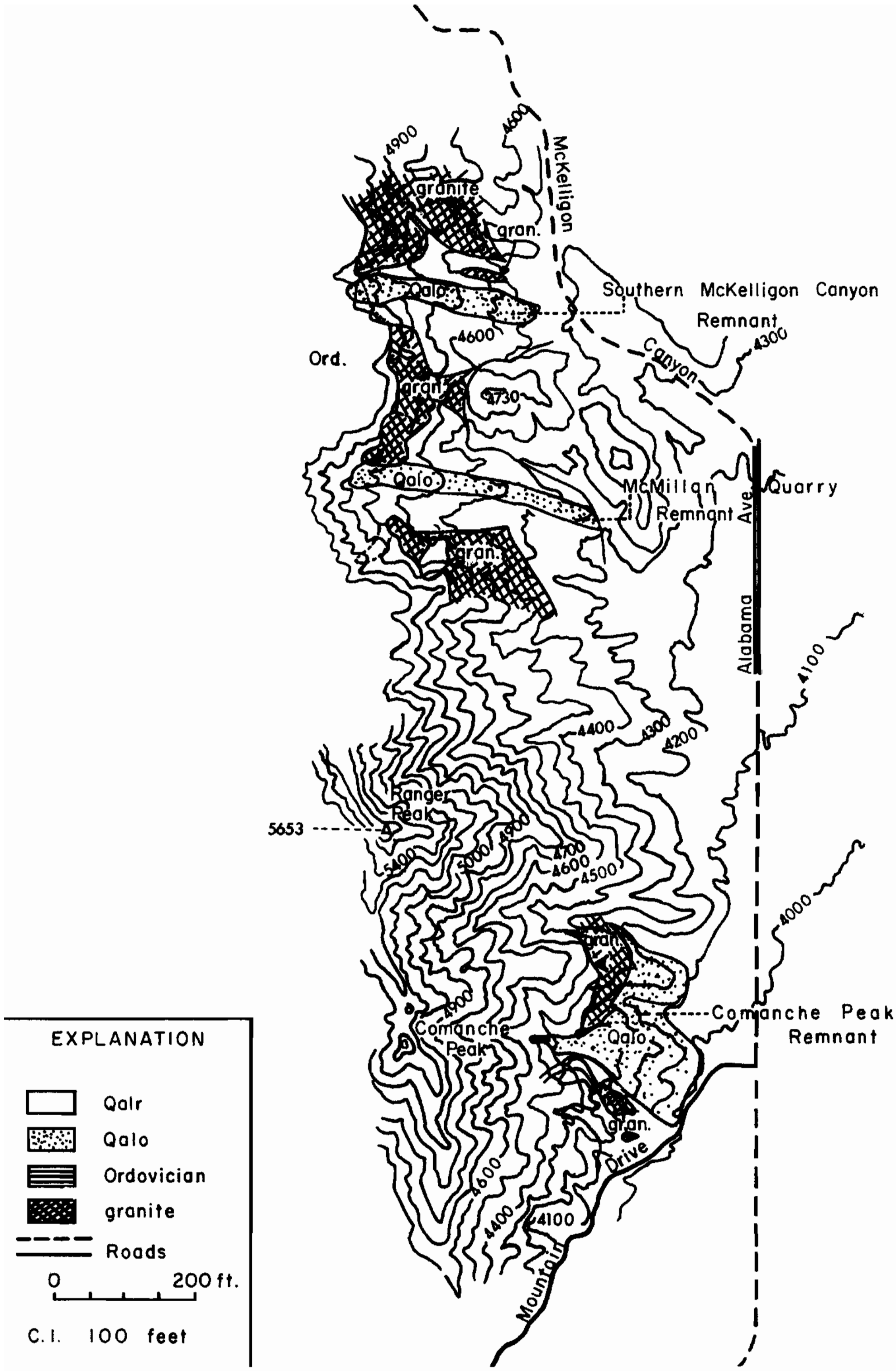

Figure 5. Geologic map of the eastern side of the southern Franklin Mountains showing remnants of early to middle Pleistocene alluvium. Qalr (modern alluvium and colluvium) extends east of the granite and/or older alluvial deposits.

surfaces project down to elevations higher than those of the fan deposits which contain fine-grained, possibly lacustrine, sediments of the upper Santa Fe Group. The deposits appear to be parts of an up-faulted old surface which exists on the east side of the range.

GEOMORPHIC CONCLUSIONS

A high-level geomorphic surface exists in the Franklin Mountains. This surface may be correlated with the Rincon surface of possible early Pleistocene age (Hawley and others, 1969), the Dona Ana surface of mid-Pleistocene age, or the slightly younger Jornada I surface also of mid-Pleistocene age. This surface extends across the western boundary fault zone of the range, has been displaced about 2 m and may have been tilted east of that fault. Since the time when this surface formed on the west side of the range, at least 100 ft of erosion into the Thunderbird rhyolite occurred at the Thunderbird, and an indeterminate but similarly thick amount of Paleozoic material was removed from the rhyolite on the west side of North Franklin Mountain. Since the time of deposition of the alluvium, gullying has lowered drainages up to 100 ft, just west of the border fault in some places, and but a few tens of feet in others close by. Stream capture, variable rates of erosion, and varying gradients are the product of transport of different types of bedrock with different types of consequent bed load. The pattern of post-high-level stream development on the west side of the Franklin Mountains is, in detail, quite complex. Its genesis is a subject of current research.

TECTONIC ANALYSIS AND CONCLUSIONS

The unbroken upper Santa Fe Group strata, barely broken older alluvial surfaces, and slightly faulted Crazy Cat slide of upper Santa Fe age indicate displacement of less than 10 ft along the western border of the Franklin Mountains since the middle, if not earlier, Pleistocene. If there has been 350 to 400 ft of relatively basin-downward displacement on the eastern side of the Franklin Mountains since upper Santa Fe Group deposition, as suggested by Sayre and Livingstone (1945), then either the Franklin Mountains have been uplifted and further tilted westward (Fig. 6a), the Franklin Mountains have not been uplifted and the strata in the Hueco bolson east of the Franklin Range have been depressed by compaction (Fig. 6b), or some combination of both uplift and compaction may have occurred.

A displacement of 400 ft (121 m) across a range width of 4880 m would change slopes by about 4 percent. Thus, gradients on the west side would be increased at most 4 percent and those on the east side would be decreased at most 4 percent. Slopes on the east of 12, 14, and 20 percent, composed of gravels consisting of clasts of Paleozoic limestone, compare with slopes on the west side of 20, 20, 23, and 18 to 20 percent. Corrected slopes are 16, 18, and 24 percent on the east side, compared to 16, 16, 19, and 14 to 16 percent on the west side. Tilting could account for this difference. However, it should also be noted that there is a direct correlation between elevation of surface and surface inclination, which is expected with a concave alluviated surface, and there is also a direct correlation between clast size and gradient.

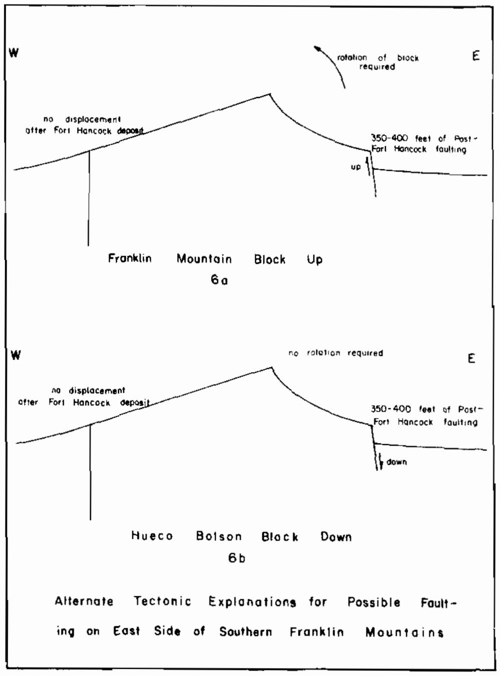

Figure 6. Alternate explanations for the presence of 400 ft of post-early-to-middle Pleistocene displacement on the east side of the Franklin Mountains and no such displacement on the west side.

Less than 2 mi east of the fault scarps mentioned by Sayre and Livingstone (1945) and Kottlowski (1958), 9000 ft (2720 m; 4000 ft, or 1200 m of clay, at least) of valley fill occur beneath Fort Bliss (Cliett, 1969, p. 210). Sediment compaction, perhaps accompanying clay desiccation, could have also produced all or part of this piedmont faulting, none of which is found in bedrock. If this is true, then the Franklin Mountains may have been essentially tectonically quiescent since the formation of both the Crazy Cat slide and the older, high-level alluvial surfaces described herein (*see* Lovejoy, 1968).

However, on the assumption that the rate of range rotation has been constant, which may not be correct, the present average dip of the range, about 35 degrees, would have taken about 15 times as long as the time required for the tilting of 4 percent, or 2.3 degrees. If the older alluvium is of early to mid-Pleistocene age it may be from 0.25 to 2.0 m.y. old (Fairbridge, 1968). Hence, range tectonism may have started between 4 and 30 m.y. ago using these assumptions. This would seem to agree with an early to late Miocene inception for the Franklin Mountain tectonics. These assumptions, however, are very tentative, and subject to many variables. For example, a decreasing rate of tilting would increase that age, perhaps placing it in the Oligocene or even late Eocene.

Further, if the orogenic uplift due to faulting has occurred at the same rate as tilting (this is yet to be demonstrated) then there has been a shortening of the crust across the Franklin Mountains of about 10 percent (cos 35 degrees) in the same period of time due to this tilting. This is a crustal shortening across the Franklin Mountains of about 500 m since the inception of range tectonics. Detailed field studies in the range indicate that the range has been deformed by compression. The western boundary fault of the range with a displacement of from 6000 to 8000 ft (*compare with* Richardson, 1909) dips east with movement up on the east. It is thus a reverse fault. A report on the geometry and tectonics of the western fault will be presented elsewhere.

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